Geotechnical Properties of Tidal Flat Muds: Responses to Tangential and Normal Stresses

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LONG-TERM GOALS

The long-term goal is a quantitative and mechanistic understanding of the response of mud flat sediments to tangential and normal stresses and how these relate to the erosion rates of mud flats.

OBJECTIVES

The rate of muddy sediment erosion is very difficult to predict, yet it is crucial to know in predicting the evolution of mud flats as a result of natural or anthropogenic perturbations. Our objective is to determine if fracture strength alone or in combination with other geotechnical properties of muddy sediments is a predictor of erodibility.

APPROACH

Working at the Willapa Bay, Washington State, USA study site:

(1) Measure the values of elastic geotechnical parameters (Young's modulus, shear strength, and fracture toughness) as functions of sediment depth, organic matter content, temperature, grain size and porosity. (B. Johnson, M. Barry)

Report Documentation Page

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(2) Establish any correlations between these various parameters, using linear elastic theory and LEFM. (B. Boudreau)

(3) Measure erodibility of the near-surface sediments using a rotary flume from the Bedford Institute of Oceanography. (P. Hill, in collaboration with Tim Milligan and others).

(4) Measure erodibility of the sediments as a function of depth using a portable flume (B. Johnson, M. Barry)

(5) Explore relationships among the measured parameters and sediment erodibility. (all group members)
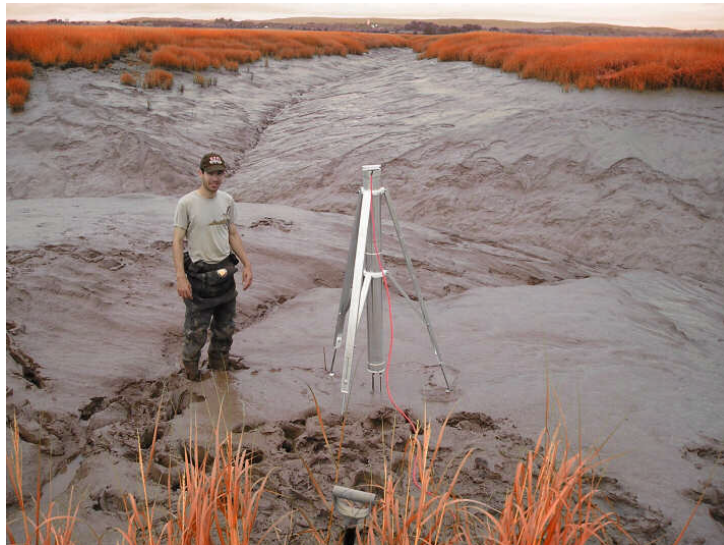
Figure 1. The fracture probe (K_{1C}) deployed in a muddy tidal flat sediment. (PhD student Mark Barry for scale.) [apparatus for measuring profiles of fracture toughness shown at a field site in the Bay of Fundy]

WORK COMPLETED

In 2009 we participated in the two DRI field experiments (March and July) at Willapa Bay, Washington. For the March 2009 field study we developed a fracture probe with greater vertical resolution to measure fracture toughness profiles in the top centimeter of sediment cores. The purpose was to provide measurements that could be used to support the interface erosion measurements made by Paul Hill, Tim Milligan, Pat Wiberg and others. We also measured fracture toughness and Young's modulus profiles using our standard probes, and we collected samples for laboratory measurements of porosity,

organic content, and particle size distribution. For July 2009 we measured fracture toughness, Young's modulus, and shear strength (shear vane). We also collected samples for sediment property measurements, and used our newly developed portable flume (figure 2) to measure erosion rates. The flume measurements were made in order to determine erodibility with depth to complement measurements of surface erodibility made by others in the DRI.

The portable flume is fitted with a stepper motor-driven piston to advance the core upward into the water flow as the sediment erodes. Feedback to trigger the advance is either visual, or through a laser sheet projected at bed level across the sediment core to an optical detector at bed level on the opposite wall. A stress sensor is located flush with the flume bed and just upstream of the core sample. In order to vary stress and gravitational forces on eroding sediment, the water flow rate and angle of the flume bed are adjustable.
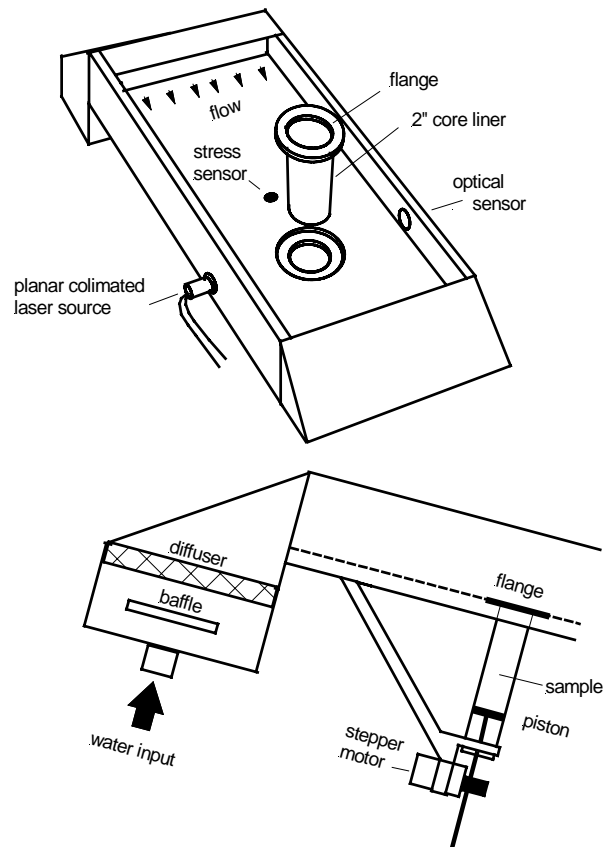

FIGURE 2. Flume design: a 2"piston core with flange fits into the flume flush with the acrylic bed. A stepper motor drives a piston that forces a sample upward in response to light transmitted across the bed. Water flow is conditioned through first impacting a baffle and then passing through a poly-propylene filter acting as a diffuser.

RESULTS

Measurements down to 20 cm depth in Willapa Bay samples typically show fracture toughness to be less than 500 N m $^{-3/2}$. This is low compared to the more dynamic Bay of Fundy where fracture toughness for sediments at comparable depths are often five times greater. Comparisons of fracture toughness with Young's modulus and shear strength profiles for the Willapa Bay samples sometimes show positive correlation (figures 3 and 4). However, for other samples Young's modulus and shear strength appear positively correlated, but then are negatively correlated with fracture toughness. This behavior is probably due to the presence of sand which has a near zero fracture toughness, but a significant Young's modulus and shear strength. Results of grain size analysis, yet to be completed, will test this explanation.

Erosion measurements on Willapa Bay samples in the flume show sand to have a high erodibility and particularly when the flume angle is steep. WIth muddier samples, near-surface erosion occurrs with millimeter sized aggregates removed in a manner that appears to be strongly influenced by biomaterials. Erosion deeper into the core produceds aggregates of 5 to 10 mm separating in what is clearly a fracture dominated process.
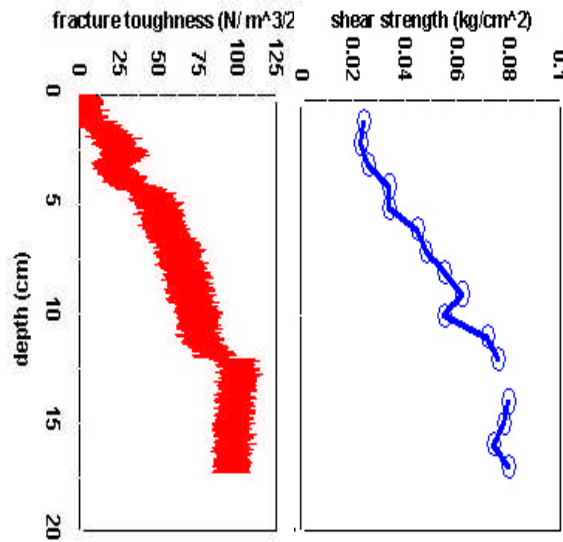

Figure 3. Willapa core CC2C collected July 18, 2009. left: fracture toughness; right: shear strength measured with a shear vane.
[fracture toughness increases from near 0 Newtons/ meter $^{3/2}$ at the sediment water interface to about 100 Newtons/ meter $^{3/2}$ at 12.5 cm depth and then remains at this fracture toughness until the end of the profile at 17.5 cm depth. Shear strength shows a similar trend, but increases from about 0.02 kg cm $^{-2}$ at 1 cm depth to near 0.08 kg cm $^{-2}$ at 12.5 cm and then remains at this value to the end of the profile at 17.5 cm]
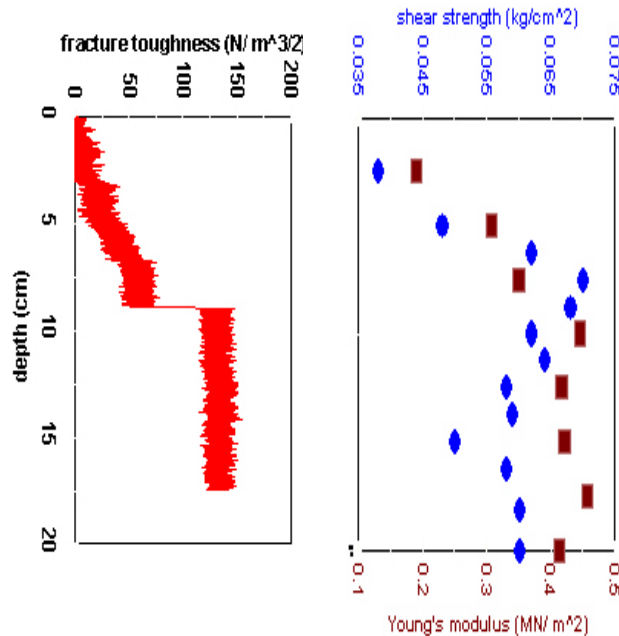
Figure 4. Willapa core CC4A collected July 19, 2009. left: fracture toughness; right: shear strength (blue), and Young's modulus (brown).
[fracture toughness is near 0 Newtons/ meter $^{3/2}$ near the sediment surface and then increases gradually to about 50 Newtons/ meter $^{3/2}$ at 9 cm depth. At about 9 cm depth the fracture toughness increases to near 150 Newtons/ meter $^{3/2}$ and remains at this value for the remainder of the profile to 17.5 cm. Measurements of Young's modulus begin at about 0.2 MN m^{-2} at 2 cm depth and rise to near 0.45 MN m $^{-2}$ at about 10 cm depth. Young's modulus remains near this maximum value for the remainder of the profile to 20 cm depth. Shear strength increases from about 0.037 kg cm $^{-2}$ at 2 cm depth to about 0.07 kg cm $^{-2}$ at about 8 cm depth. The value then gradually declines to 0.6 kg cm $^{-2}$ at 14 cm depth and remains near this value until the end of the profile at 20 cm depth.]

IMPACT/APPLICATIONS

Our results will lead to better prediction of tidal flat stability and relevant geotechnical information, like trafficability.

RELATED PROJECTS

None.

PATENTS

We are in the process of patenting the fracture probe and are waiting to publish results when the patent is pending.